YEARLY PROGRESS REPORT

Project Title: Gas Fluxing of Aluminum: A Bubble Probe for Optimization of Bubbles/Bubble Distribution and Minimization of Splashing/Droplet Formation

Covering Period: August 21, 2002 to August 20, 2002

Date of Report: October 25, 2002

Recipient: Department of Materials Science and Engineering
University of California
Berkeley, CA 94720-1760

Award Number: DE-FC07-01ID14192

Subcontractors: Not applicable.

Other Partners: Alcoa Inc.

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Project Team: John Yankeelov, Corleen Chesonis, J.W. Evans, Autumn Fjeld

Project Objective:

A capacitance probe has been developed for the detection of bubbles in liquid aluminum and the measurement of their size, frequency and velocity. It is proposed to apply this probe to measure the bubble dispersion and size in industrial scale gas fluxing units in collaboration with Alcoa. Knowledge gained in this way can stimulate the development of improved fluxing units through more uniform dispersion of bubbles and optimum bubble size. Furthermore, the bubble data will be used in advancement of existing mathematical models for fluxing so that these models can optimize the operation of present fluxing units and the development of future units. The objective will be to determine how bubble characteristics (and therefore the bubble-aluminum interfacial area that controls fluxing kinetics, chlorine utilization efficiency and unit throughput) depend of design and operating parameters. Simultaneously, laboratory scale investigation of liquid spraying by bubbles bursting at the melt surface will start. This phase of the investigation is aimed at avoiding throughput limitations due to splashing and spraying as fluxing gas is injected. It will use high-speed digital cameras to quantify spraying and determine conditions under which it can be minimized.

Background:

This work is an investigation seeking better ways to remove impurities from aluminum from both primary production and the recycling of consumer scrap, such as beverage cans. Presently these impurities (Na, Ca, Mg, Li etc.) are removed by poorly controlled injection of gases containing chlorine into the molten metal. Only a fraction of the injected gas reacts and the excess is reported as emissions of chlorides such as toxic HCl. The intention is to improve the technology to eliminate this waste (saving on the energy entailed in the chlorine production and reducing pollution) by better dispersion of the injected gas throughout the metal. The work will also determine how best to avoid splashing and spraying resulting from gas injection at high rates. In this way it is expected that the throughput of aluminum can be increased with resultant increase in productivity and reduction in heat losses per lb. of aluminum, saving additional energy. Reduced spraying is also expected to reduce particulate emissions from fluxing operations. A combination of mathematical modeling and experimental measurements will be employed to determine ways to optimize fluxing operations. This work will be carried out in collaboration with Alcoa.

Previous studies of chlorine fluxing have clearly shown that the rate of removal of impurities during fluxing is dependent on the size, dispersion throughout the melt and residence time of the gas bubbles injected into molten aluminum. Consequently any fundamental study of fluxing, at either the laboratory or commercial scale, should entail measurement of these bubble parameters. No measurements have been reported on aluminum at the commercial scale and only a few laboratory investigations have been done. From 1995 to 1998 an investigation on chlorine fluxing of aluminum was carried out at Berkeley. Experimental data were collected and compared to a mathematical model that was concurrently developed. The model was based on an ideal bubble size distribution which is unlikely to represent the bubble distribution in an industrial fluxing unit. With this discrepancy in mind a capacitance probe was developed to detect bubbles and measure their size and velocity. The current project has refined the capacitance probe system for use in an industrial setting. Data gathered from industrial fluxing units can then be used as an aid in developing a mathematical model to chlorine fluxing in the aluminum industry.

Status:

Work to date has consisted of gathering bubble data at Alcoa Technical Center and in the laboratory and fine tuning the equipment and procedures necessary to accomplish this task. Recent work has focused on processing the data through visual analysis, as well as developing signal recognition and deconvolution software. A week in July (the third of four visits to Alcoa to date) was spent gathering data at Alcoa and proved to be a very successful trip. A key item in the success of the trip was a new measurement circuit or "capacitance meter" which was redesigned and built to withstand an industrial environment. The capacitance meter receives signals from the probe when immersed in molten aluminum. Due to the increased performance of the overall capacitance probe system we were able to sustain long periods of measurement time in the molten aluminum. This increased performance provided further testing of the probe due its ability to withstand hours of continual immersion in the aluminum melt. We were able to identify ways in which the probe could be improved upon to ensure its reliability in an industrial setting. This included using new materials in the capacitance probe, increasing its mechanical durability.

A conference paper on cumulative work examining bubble distribution and behavior in both a stagnant, laboratory scale crucible of molten metal and in Alcoa's industrial fluxing units was recently submitted for publication and should appear in Light Metals 2003. Results will also be presented at the Minerals, Metals & Materials Society conference in March 2003. The results from this visit to Alcoa, while demonstrating the successful application of the probe in a working fluxing unit, are the initial findings of this investigation. The following is a summary of the paper submitted to Light Metals 2003. Results relevant to Alcoa's specific fluxing unit have been omitted for this report, but can be found after publication.

Experimental Procedures

The capacitance probe used for detecting bubbles in liquid metals is depicted in Fig. 1. It consists of one or two nichrome wires contained within a thin walled, double-bore alumina tube of the kind commonly used for making thermocouples. This inner alumina tube protrudes 3 to 4 cm from the body of the probe, forming the sensing portion of the probe. The end of the tube is sealed with a ceramic paste to isolate the wires from the molten aluminum. The body of the probe is shielded from stray capacitance by a 1.3 cm OD stainless steel sheath, which is protected from the aluminum by an outer thick walled alumina tube. [In this way the only part of the probe in contact with aluminum is of alumina and the probe can withstand several hours of immersion in aluminum.] The wires connect to a specially designed circuit, effectively a capacitance meter that detects small changes in capacitance at a sampling rate of 1,000 Hz. Making use of the sensitivity of Wheatstone type bridge, the circuit is able to detect capacitance changes on the order of picofarads. The capacitance circuit sends the measured signal to a laptop computer, which records the signal in 20 second intervals. If only one wire is used in the probe then a second electrical connection is made to the aluminum. However, a more convenient technique is to have two wires in the probe and to measure the capacitance between these two wires. That capacitance is affected by the wire-melt capacitance and therefore bubbles can be detected with no direct connections to the melt.

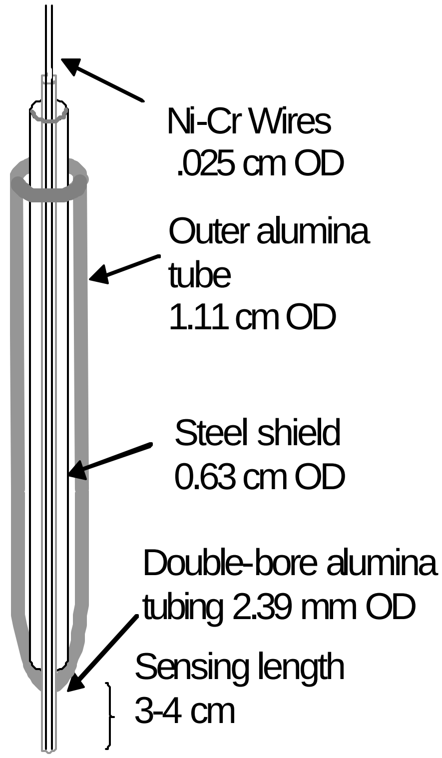


Figure 1. Depiction of the capacitance probe used to detect bubbles in molten metal.

Fig. 2 is a schematic diagram showing the ideal signal response when a bubble passes over the sensing region of the probe. As a bubble comes in contact with the probe, the effective contact area between the Ni-Cr wires and the Al melt decreases, thus the capacitance decreases. As the bubble rises to touch the bubble tip the capacitance starts to change, reaching a constant value when the bubble is completely skewered on the sensing length. The capacitance then returns to the baseline value when the bubble has passed off the sensing length.

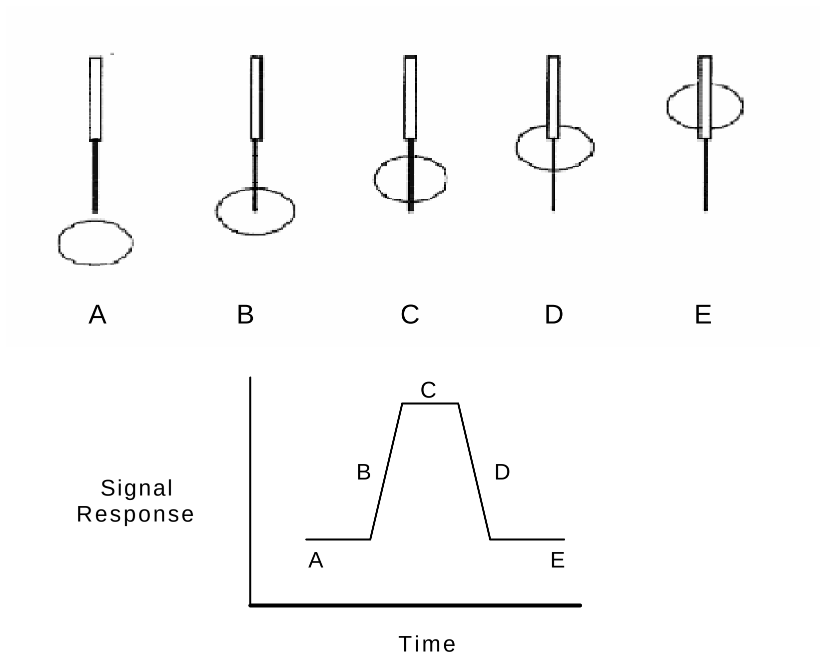
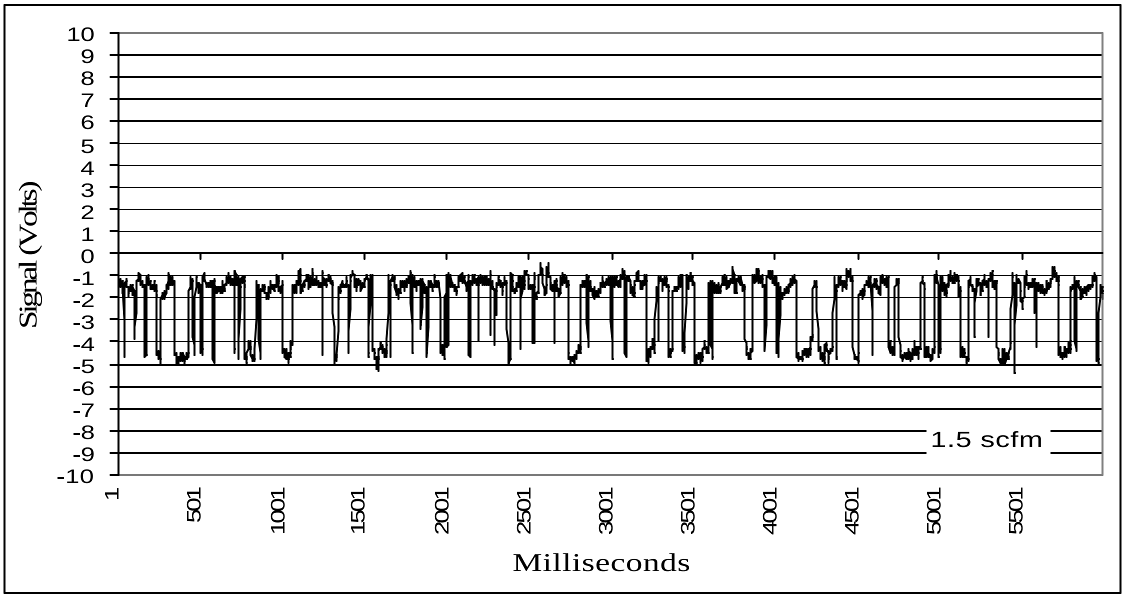


Figure 2. Depiction of bubble-probe interaction and ideal signal response. Capacitance begins to change as bubble initially makes contact with the sensing length of the probe, reaching a saturation value, and then returns to the baseline signal as the bubble leaves the probe.

Observations/Results

The experimental work carried out in collaboration with Alcoa will be published in Light Metals 2003 and will not be detailed here. Additionally, some details of the work are considered proprietary by Alcoa and will not be discussed as yet. The results presented in the Light Metals paper, while demonstrating the successful application of the probe in a working fluxing unit, are the initial findings of this investigation.

Results in Fig. 3 were obtained in a laboratory furnace at the University of California at Berkeley, prior to a trip to Alcoa. Aluminum was melted in a small crucible, 10 cm wide and 16 cm deep, into which argon was injected through a j-shaped tube. The probe was positioned in the center of the melt 3 to 5 cm above the nozzle of the gas tube. In the lower plot, the output from the capacitance measuring circuit is plotted versus time for a six second interval with the gas injected at 0.5 scfm. Each large downward “spike” corresponds to one bubble passing the probe sensing length. [Both Fu and Evans (1) and Mittal (2) have demonstrated this by incorporating a microphone in the gas supply line to detect a bubble detachment.] Over 30 bubbles are distinguishable in this plot, while at least 60 bubble signals can be identified over the same time period in the upper half of the figure, where the gas flow rate is higher by a factor of three.



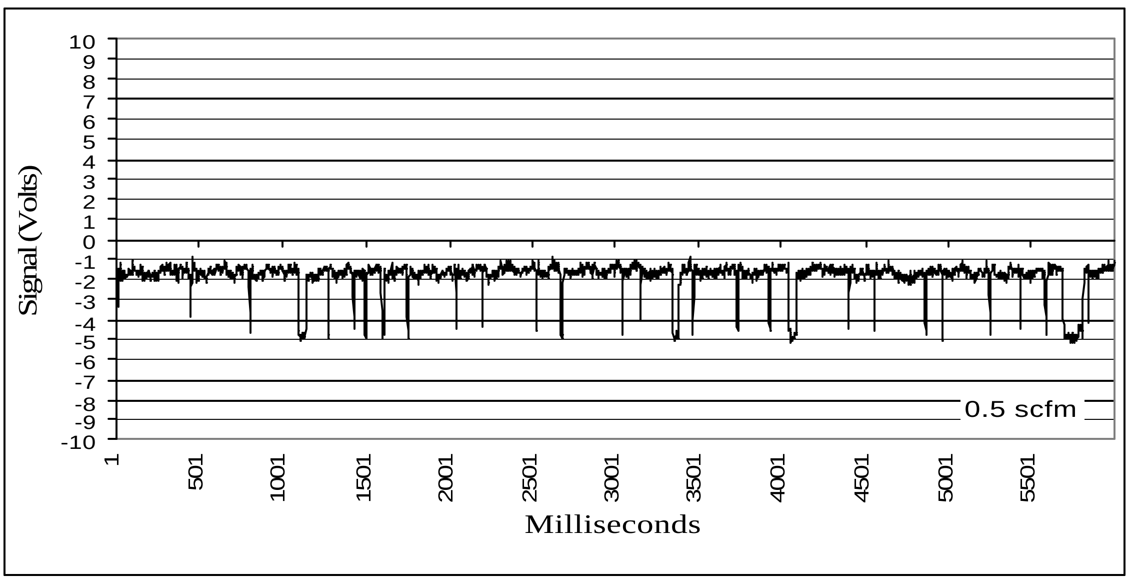


Figure 3. Results from laboratory tests at UC Berkeley. The plots show the bubble frequency for Ar gas injected into a small crucible of molten aluminum for an 8 second time period. Data in the upper plot was taken at a gas flow rate of 1.5 scfm and has a much higher bubble frequency than the lower plot, where the gas flow rate was 0.5 scfm.

Conclusions

The bubble probe described here has shown itself to be a rugged device for detecting bubbles in molten aluminum. The probe detects the presence of a bubble by the change in the capacitance of the probe as a bubble moves over its sensing region. In theory the probe is capable of measuring bubble size and velocity, as well as the frequency of occurrence of bubbles at the probe location. In the present work, only bubble frequency has been reported.

Recent data gathering trips to have been very successful, increasing confidence in the performance of the capacitance probe and measurement circuit. Few problems were encountered and the capacitance probe was more robust due to improvements incorporated throughout the past year. With the success of this last trip, we should have sufficient data to characterize the bubble distribution in Alcoa's fluxing units. Thus, unless analysis of the data indicates further investigation is needed, this portion of the project may be completed.

References

1. Q. Fu and J. W. Evans, "A Capacitance Probe for Measurement of Bubbles in Molten Metals", ISIJ International, vol. 39, p309 (1999).
2. N. Mittal, M.S. thesis, University of California, Berkeley, 2002

Plans for Next Year:

The next few months will include finishing the analysis of data gathered at Alcoa. An additional data gathering trip may be a possibility if it is determined additional or duplicate data is needed to accurately characterize the bubble distribution in Alcoa's fluxing unit. Further development and use of signal processing software will be carried out to extract the maximum information from existing data. The portion of this project involving mathematical modeling will begin and planning for experimental work on splashing and spraying of metal during gas fluxing will start.

Patents: Not applicable.

Publications/Presentations:

The following paper has been submitted for publication in Light Metals 2003:
"Measurements of bubble dispersion and other bubble parameters in a gas fluxing unit at Alcoa using a capacitance probe."

Milestone Status Table: This should be a complete list of project milestones, anticipated completion dates and actual completion dates. The milestone identification number should correspond to the task numbers in your agreement to aid in tracking (example below).

ID Number	Task / Milestone Description	Planned Completion	Actual Completion	Comments
1.1	Gather bubble data at Alcoa Tech Center	12/2001, 6/2002, 2/2003	10/02	Additional visits made Alcoa
1.2	Bubble Recognition and Deconvolution Software	3/2003		
2.1	Fluxing Model for non-agitated melt	6/2003		
2.2	Develop FLUENT model to simulate agitated fluxing	12/2003		
2.3	Utilize FLUENT and/or existing model to predict fluxing behavior	12/2003		
2.4	Development of fluxing control strategy	5/2004		

3.1	Construct lab apparatus to study splashing & spraying	6/2003		
3.2	Perform lab measurements of splashing & spraying	12/2003		
4	Final Report & Publication	11/04		

Budget Data : The approved spending should not change from quarter to quarter. The actual spending should reflect the money actually spent on the project in the corresponding periods.

			Approved Spending Plan			Actual Spent to Date*		
Phase / Budget Period			DOE Amount	Cost Share	Total	DOE Amount	Cost Share	Total
	From	To						
Year 1	8/21/01	8/20/02	$76,326	20,000	96,326	72,803	2,483	74,886
Year 2	8/21/02	8/20/03	$83,937	20,000	103,937			
Year 3	8/21/03/	8/20/04	$78,526	20,381	98,907			
Year 4								
Year 5								
		Totals	$238,798	60,381	299,170			

* To 8/31/02. Excludes cost share in kind.

Spending Plan for the Next Year:

Month	Estimated Spending
Should be completed for each month of the next year	
09/02	$8,661
10/02	$8,661
11/02	$8,661
12/02	$8,661
01/03	$8,661
02/03	$8,661
03/03	$8,661
04/03	$8,661
05/03	$8,661
06/03	$8,661
07/03	$8,661
08/03	$8,666